specification disclosure. Attached hereto is a marked-up version of the changes made to claims 1 and 3-7 by the current amendment. The attached pages are captioned **"VERSION WITH MARKINGS TO SHOW CHANGES MADE."**

Claims 1-7 remain in the application for consideration by the examiner. These claims were rejected under 35 U.S.C. § 112, second paragraph, as being indefinite. The Official action objected to several phrases in these claims as lacking antecedent basis. In the foregoing amendments, these claims were amended to set forth proper antecedent basis for all the elements defined therein. Therefore, applicant respectfully requests that the examiner reconsider and withdraw this rejection.

On pages 3-4 of the Official action, claims 1-7 were rejected under 35 U.S.C. § 102(e) as being anticipated by U.S. patent number 6,381,257 B1 of Ershov *et al.* (Ershov). The present application has an effective filing date of July 5, 1999, based on a claim for foreign priority under 35 U.S.C. § 119. This effective filing date for the present application is earlier than the earliest effective filing date of Ershov, which is December 10, 1999. Therefore, Ershov is not a proper reference against the claims in this application under any section of 35 U.S.C. § 102.

Applicant is attaching hereto a verified English translation of the priority document, Japanese patent application No. 11-190490, filed July 5, 1999, upon which the present application claims priority under 35

U.S.C. § 119. For the foregoing reasons, applicant respectfully requests that the examiner reconsider and withdraw the rejection of claims 1-7 over the teachings of Ershov.

On pages 4-5 of the Official action, claims 1-7 were rejected under 35 U.S.C. § 102(e) as being anticipated by U.S. patent number 6,240,117 B1 of Gong *et al.* (Gong). The Official action stated that Gong discloses a laser chamber (Fig. 4-5, 8-9) filled with laser gas to which a predetermined discharge voltage is applied between a cathode (4) and anode (4) causing oscillation of laser light. The Official action further stated that Gong discloses that the pressure of laser is set equal to or lower than a determined value such that the bandwidth is narrowed to a desired value (Fig. 7). The examiner continued that Gong discloses the discharging mode in a longitudinal or transverse direction (Fig. 4-5 and 8-9 and col. 9, lines 7-22).

Applicant respectfully submits that the teachings of Gong do not contemplate or suggest the invention as set forth in any of the present claims within the meaning of 35 U.S.C. § 102 or 35 U.S.C. § 103.

The presently claimed invention is directed to a relationship between ***total*** pressure of laser gas and bandwidth. This is defined in the amended claims and described in applicant's specification disclosure. See, for example, the last paragraph on page 11 of applicant's specification disclosure. On the other hand, the teachings of Gong, as well as those of Ershov, are concerned with a relationship between

partial pressure fluorine gas and bandwidth. The relationship between total pressure of laser gas and bandwidth and the relationship between partial pressure fluorine gas and bandwidth are based on different principles and rules of science. Therefore, applicant respectfully submits that the discussion concerning partial pressure of fluorine gas within the teachings of Gong would not motivate one of ordinary skill in the art to a relationship between total pressure of laser gas and bandwidth, as set forth in the present claims. For similar reasons, the teachings of Gong do not provide any suggestion to one of ordinary skill in the art, which could motivate such a person of ordinary skill in the art to believe that somehow modifying the total pressure of laser gas would have any effect on the bandwidth.

For the foregoing reasons, applicant respectfully submits that there are significant differences between the teachings of Gong and the presently claimed invention. Therefore, applicant respectfully request that the examiner reconsider and withdraw the rejection of claims 1-7 over the teachings of Gong.

In view of the foregoing amendments and remarks, favorable consideration and allowance of claims 1-7 are respectfully requested.

While it is believed that the present response places the application in condition for allowance, should the examiner have any comments or questions, it is respectfully requested that the undersigned be telephoned at the below listed number to resolved any outstanding issues.

In the event this paper is not timely filed, applicant hereby petitions for an appropriate extension of time. The fee therefor, as well as any other fees which may become due, may be charged to our deposit account No. 22-0256.

Respectfully submitted,
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Attachment: Verified English translation of Japanese patent application No. 11-190490.

VERSION WITH MARKINGS TO SHOW CHANGES MADE

IN THE CLAIMS:

Claims 1 and 3-7 were amended as follows:

-- 1. (Amended) An ultra-narrow band fluorine laser apparatus comprising a laser chamber which is filled with a laser gas including fluorine and to which a predetermined discharge voltage is applied between a cathode and an anode thereof for causing a fluorine laser to oscillate laser light to be supplied as an exposure light source of an exposure apparatus, wherein [the] total pressure of said laser gas is set equal to or lower than a predetermined value such that a bandwidth of laser light oscillated by said laser chamber is narrowed to a desired value. --

-- 3. (Amended) An ultra-narrow band fluorine laser apparatus according to Claim 1, wherein the total pressure of said laser gas is set equal to or lower than 1 atm. --

-- 4. (Amended) An ultra-narrow band fluorine laser apparatus according to Claim 1, wherein the interval between the cathode and anode [said two electrodes] is set at a predetermined length to maintain glow discharge without causing dielectric breakdown between said cathode and anode when the total pressure of said laser gas is set equal to or lower than said predetermined value. --

-- 5. (Amended) An ultra-narrow band fluorine laser apparatus according to Claim 4, wherein <u>a</u> [the] discharging mode for causing said glow discharge is longitudinal discharge in which discharge occurs in the same direction as <u>an</u> [the] optical axis of laser light oscillated in said laser chamber. --

-- 6. (Amended) An ultra-narrow band fluorine laser apparatus according to Claim 1, further comprising an oscillator including said laser chamber and an amplifier for amplifying [the] power of laser light oscillated by the oscillator and supplying it as an exposure light source for said exposure apparatus. --

-- 7. (Amended) An ultra-narrow band fluorine laser apparatus according to Claim 6, wherein, <u>a</u> [the] discharging mode of the glow discharge caused between the cathode and anode in said laser chamber is transverse discharge in which discharge occurs in a direction perpendicular to <u>an</u> [the] optical axis of laser light oscillated in said laser chamber and wherein the transverse discharge decreases the discharge voltage applied between said cathode and anode to a desired voltage such that glow discharge is maintained without causing dielectric breakdown between <u>the cathode and anode</u> [said two electrodes]. --

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[Title of the Invention] ULTRA-NARROW BAND FLUORINE LASER APPARATUS

[Number of Claims] 7

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[Name of Article]	Abstract 1
[Necessity of Proof]	Proof Necessary

[Designation of Document] Specification

[Title of the Invention] ULTRA-NARROW BAND FLUORINE LASER APPARATUS

[Claims]

[Claim 1] An ultra-narrow band fluorine laser apparatus comprising a laser chamber which is filled with a laser gas including fluorine and to which a predetermined discharge voltage is applied between a cathode and an anode thereof for causing a fluorine laser to oscillate laser light to be supplied as an exposure light source of an exposure apparatus, which is characterized in that

the pressure of said laser gas is set equal to or lower than a predetermined value such that a waveband of laser light oscillated by said laser chamber is narrowed to a desired value.

[Claim 2] An ultra-narrow band fluorine laser apparatus according to Claim 1, which is characterized in that said waveband is narrowed to a desired value within the range from 0.2 to 0.3 pm.

[Claim 3] An ultra-narrow band fluorine laser apparatus according to Claim 1, which is characterized in that the pressure of said laser gas is set equal to or lower than 1 atm.

[Claim 4] An ultra-narrow band fluorine laser apparatus according to Claim 1, which is characterized in that the interval between said two electrodes is set at a

predetermined length to maintain glow discharge without causing dielectric breakdown between said cathode and anode when the pressure of said laser gas is set equal to or lower than said predetermined value.

[Claim 5] An ultra-narrow band fluorine laser apparatus according to Claim 4, which is characterized in that the discharging mode for causing said glow discharge is longitudinal discharge in which discharge occurs in the same direction as the optical axis of laser light oscillated in said laser chamber.

[Claim 6] An ultra-narrow band fluorine laser apparatus according to Claim 1, which is characterized by further comprising an oscillator including said laser chamber and an amplifier for amplifying the power of laser light oscillated by the oscillator and supplying it as an exposure light source for said exposure apparatus.

[Claim 7] An ultra-narrow band fluorine laser apparatus according to Claim 6, which is characterized in that the discharging mode of the glow discharge caused between the cathode and anode in said laser chamber is transverse discharge in which discharge occurs in a direction perpendicular to the optical axis of laser light oscillated in said laser chamber, and

the transverse discharge decreases the discharge voltage applied between said cathode and anode to a desired

voltage such that glow discharge is maintained without causing dielectric breakdown between said two electrodes.

[Detailed Description of the Invention]

[0001]

[Technical Field to which the Invention belongs]

The present invention relates to an ultra-narrow band fluorine laser apparatus for supplying laser beams from a fluorine laser as an exposure light source of an exposure apparatus.

[0002]

[Prior Art]

There are various requirements for the performance of a lithographic exposure apparatus including resolution, alignment accuracy, processing capability and reliability of the apparatus. Resolution R which directly relates to fineness of a pattern is expressed by $R = k \cdot \lambda / NA$ where k represents a constant; λ represents an exposure wavelength; and NA represents the numerical aperture of a projecting lens. Therefore, resolution becomes more preferable, the shorter the exposure wavelength λ.

[0003]

In exposure machines according to the related art, therefore, an i-beam (having a wavelength of 365 nm) from a mercury lamp or a krypton fluorine (KrF) excimer laser having a wavelength of 248 nm is used as a exposure machine light source.

The machines are therefore referred to "i-beam exposure machines" or "KrF exposure machines".

[0004]

Exposure machines utilizing an argon fluorine (ArF) excimer laser having a wavelength of 193 nm as an exposure light source have been put in use as next generation exposure machines for fine processing. Those machines are referred to as "ArF exposure machines". An ArF exposure machine uses a narrow band ArF excimer laser in a waveband as small as about 0.6 pm and an achromatic lens made of two types of materials as a reducing projection optical system.

[0005]

Further, referring to next generation lithographic exposure machines to replace the above-described ArF exposure machines, studies are in progress on fluorine exposure machines utilizing a fluorine laser having a wavelength of about 157 nm as a light source.

[0006]

A fluorine laser has two oscillation beams (also referred to as "oscillation lines") with different wavelengths and optical intensity. It is said that those beams have wavelengths of 157.5233 nm and 157.6299 nm respectively and that each of the oscillation beams has a waveband of about 1 pm.

[0007]

When such a fluorine laser is used for exposure, in general, it is considered advantageous to use only one line with a wavelength (157.6299 nm) having high intensity (hereinafter referred to as "single line configuration"), and one or two prisms have been used for such a single line configuration according to the related art.

[0008]

However, since the line has a waveband of about 1 pm, it is considered necessary to use a catadioptric reducing projection optical system which is said to be usable in a waveband ten times wider than that of totally refractive optical system utilizing only a lens, as a reducing projection optical system of an exposure machine.

[0009]

Operating characteristics and the like of fluorine lasers are described, for example, in "The Review of Laser Engineering, Vol. 19, No. 11, pp. 2-24" (reference 1).

[0010]

Results of experiments on the one line configuration are reported in, for example, "SPIE, 24th International Symposium on Microlithography, Feb. 1999" (reference 2).

[0011]

[Problem that the Invention is to solve]

A catadioptric type system as described above necessitates a new design because it is different from

refractive reducing projection optical systems formed by only lenses commonly used in conventional exposure machines (i.e., ArF exposure machines), which has resulted more problems in this type of system than in a totally refractive reducing projection optical system.

[0012]

For the reasons described below, it has been difficult to provide an oscillation beam in a waveband as narrow as about 0.2 to 0.3 pm which is regarded usable in a totally refractive reducing projection optical systems which are more advantageous than the catadioptric type.

[0013]

While a partial reflection film must be used in an etalon or the like whose band can be narrower than that in the case where a prism is used, such a partial reflection film may not provide sufficient light-resisting strength.

[0014]

That is, in a laser with a short wavelength like a fluorine laser (i.e., a laser having a high photon energy), since a great amount of laser light is absorbed by many optical materials, even a small amount of impurity can cause damage of a partial reflection film provided on an etalon or the like attributable to a temperature rise beyond the melting point thereof because of the absorption of laser light by the optical materials forming the etalon.

[0015]

Further, while a substrate having a high surface accuracy is required for an etalon, for example, a substrate (optical material) usable in a wavelength λ = 157nm of a fluorine laser and whose base material is calcium fluoride results in a problem in that it is difficult to achieve surface accuracy of λ/100 which is normally required for an etalon.

[0016]

It is an object of the invention to provide an ultra-narrow band fluorine laser apparatus having a line width as narrow as 0.2 to 0.3 pm without using an element such as an etalon for achieving a narrow band.

[0017]

[Means for Solving the Problem, Operation and Advantage]

In order to achieve the above-described object, according to a first aspect of the invention, there is provided an ultra-narrow band fluorine laser having a laser chamber which is filled with a laser gas including fluorine and to which a predetermined discharge voltage is applied between a cathode and an anode thereof for causing a fluorine laser to oscillate laser light to be supplied as an exposure light source of an exposure apparatus, characterized in that the pressure of the laser gas is set equal to or lower than a predetermined value such that a waveband of laser light oscillated by the laser

chamber is narrowed to a desired value.

[0018]

According to a second aspect of the invention, there is provided an apparatus according to the first aspect, characterized in that the waveband is narrowed to a desired value within the range from 0.2 to 0.3 pm.

[0019]

According to a third aspect of the invention, there is provided an apparatus according to the first aspect, characterized in that the pressure of the laser gas is set equal to or lower than 1 atm.

[0020]

According to a fourth aspect of the invention, there is provided an apparatus according to the first aspect, characterized in that the interval between the two electrodes is set at a predetermined length to maintain glow discharge without causing dielectric breakdown between the cathode and anode when the pressure of the laser gas is set equal to or lower than the predetermined value.

[0021]

According to a fifth aspect of the invention, there is provided an apparatus according to the fourth aspect, characterized in that the discharging mode for causing the glow discharge is longitudinal discharge in which discharge occurs in the same direction as the optical axis of laser light

oscillated in the laser chamber.

[0022]

According to a sixth aspect of the invention, there is provided an apparatus according to the first aspect, characterized in that it further has an oscillator including the laser chamber and an amplifier for amplifying the power of laser light oscillated by the oscillator and supplying it as an exposure light source for the exposure apparatus.

[0023]

According to a seventh aspect of the invention, there is provided an apparatus according to the sixth aspect, characterized in that the discharging mode of the glow discharge caused between the cathode and anode in the laser chamber is transverse discharge in which discharge occurs in a direction perpendicular to the optical axis of laser light oscillated in the laser chamber and in that the transverse discharge decreases the discharge voltage applied between the cathode and anode to a desired voltage such that glow discharge is maintained without causing dielectric breakdown between the two electrodes.

[0024]

The first, second, third, sixth and seventh aspects of the invention will now be described with reference to Figs. 1 through 3.

[0025]

As shown in Fig. 1, in an ultra-narrow band fluorine laser apparatus 100, a laser chamber 15 is provided in a stable type resonator constituted by an output mirror 13 and a totally reflecting mirror 14, and the chamber 15 is filled with a laser gas including fluorine at about 0.8 atm. As a result, when discharge (glow discharge) is caused between electrodes in the laser chamber 15 to oscillate the laser, laser light L10 in a waveband of about 0.3 pm (see Fig. 2) is obtained.

[0026]

The laser power of the laser light L10 is as small as 1 mJ or less and is not usable for exposure as it is.

[0027]

The power of the laser light L10 from an oscillator 11 is increased by an amplifier 12. Specifically, the laser light L10 enters through a concave mirror 17 with a hole and is amplified as it travels in a laser chamber 18, and laser light L20 is obtained around a convex mirror 16.

[0028]

Discharge is caused in a transverse excitation system in the oscillator 11. Specifically, it is a system in which discharge is caused across the optical axis of the laser light in the laser chamber 15 (in a direction perpendicular to the direction of the optical axis). In this transverse excitation system, since the interval between the cathode and anode is small (e.g., in the range from 10 to 20 mm), the discharge

voltage must be low to prevent occurrence of arc discharge between the electrodes when the gas pressure is decreased. This results in a reduction of the laser power. For example, when the gas pressure is decreased from 4 atm to 1 atm, the discharge voltage must be decreased from about 20 KV to about 10 KV.

[0029]

Fig. 3 is a graph showing dependence of the laser output on discharge voltages. In the laser chamber 15, a laser operation occurs within the shaded range indicated by reference number 31 in Fig. 3. As understood by referring to Fig. 3, when the gas pressure is decreased from 4 atm to 1 atm, the discharge voltage in the laser chamber must be decreased at a degree that causes no arc discharge, which also results in a reduction in the laser power.

[0030]

While the laser light L20 obtained by amplifying the laser light L10 whose power has been thus reduced with the amplifier 12 has a waveband of about 0.3 pm because it has a spectrum similar to that of the laser light L10, the laser power has been increased to 10 mJ or more. That is, the laser light L20 has sufficient power to use for exposure.

[0031]

As described above, in the first and second aspects of the invention, the waveband of an oscillation beam from a

fluorine laser can be decreased to generate laser light having a band as narrow as 0.3 pm or less without using an element to provide a narrow band like an etalon.

[0032]

Since the band of laser light from a fluorine laser is narrowed with the pressure of the laser gas reduced (e.g., reduced to 1 atm), an oscillation beam in the narrowed band is located substantially in the middle of the initial spectral distribution. That is, since no fluctuation of a central wavelength of the oscillation beam with a narrow band occurs as a result of a temperature rise at the band-narrowing element, there is no need for stabilizing means for stabilizing the wavelength. This makes it possible to simplify the laser apparatus.

[0033]

In the third aspect of the invention, since the pressure of a laser gas is 1 atm or less, it is possible to prevent leakage of fluorine gas (which is a gas harmful to a human body) from a laser chamber.

Further, in the sixth and seventh aspects of the invention, a first oscillator decreases a waveband to about 0.3 pm and, even when laser light having low laser power is output, the laser power can be amplified by a second amplifier.

[0034]

The fourth and fifth aspects of the invention will now

be described with reference to Fig. 4.

[0035]

As shown in Fig. 4, an ultra-narrow band fluorine laser apparatus 200 has a stable type resonator which is a resonator constituted by an output mirror 21 and a totally reflecting mirror 22 and containing a laser chamber 23 and employs a longitudinal excitation system in which a pair of electrodes, i.e., a cathode 24 and an anode 25 are arranged in the laser chamber 23 in a direction in parallel with laser light L30, i.e., the direction of the optical axis of the laser light L30. The shaded part indicated by reference number 201 is a discharge area. A laser gas flows in the shaded part in a direction perpendicular to the plane of Fig. 4, and a fan 26 is provided for this purpose.

[0036]

Since the ultra-narrow band fluorine laser apparatus 200 employs such a longitudinal excitation system, the interval between the cathode 24 and anode 25 is incomparably longer than that in a normal transverse excitation system. For example, while the electrode interval in a normal transverse excitation system is in the range from 10 to 20 mm, the electrode interval can be extended to about 1000 mm in a longitudinal excitation system, which means that the electrode interval can be 50 to 100 times longer than that in the related art.

[0037]

Therefore, arc discharge is unlikely to occur and glow discharge can be maintained even if the pressure of the laser gas charged in the laser chamber 23 is very low.

[0038]

As described, in the fourth and fifth aspects of the invention, since longitudinal discharge is used in which discharge occurs in the same direction as the direction of the optical axis of oscillated laser light, a long interval between the cathode and anode, i.e., a long discharge length can be set. As a result, arc discharge is unlikely to occur and glow discharge can be maintained even if the laser gas pressure is decreased.

[0039]

[Mode for Carrying Out the Invention]

A preferred embodiment of the invention will now be described with reference to the accompanying drawings.

[0040]

Fig. 1 is an illustration of a configuration of an ultra-narrow band fluorine laser apparatus 100 according to the present embodiment, and Fig. 2 is a graph showing the dependence of a waveband on gas pressures.

[0041]

The ultra-narrow band fluorine laser apparatus 100 is adapted to perform a laser operation with the total pressure of a laser gas (hereinafter referred to as "gas pressure") of

the fluorine laser set equal to or lower than 1 atm and to generate laser light whose waveband is narrowed to 0.3 pm.

[0042]

Prior to a description on the ultra-narrow band fluorine laser apparatus 100, an explanation will be made on why the waveband can be narrowed to 0.3 pm at a gas pressure of 1 atm or less.

[0043]

In general, the spectral configuration of a fluorine laser is thought to be the Gaussian type, and a waveband $\Delta\lambda$ of the same is expressed by Equation 1.

[0044]

[Su 1]

$$\Delta\lambda = \frac{\sqrt{\ln 2/\pi} \quad \lambda^2}{4\pi\tau_{sp}C\sigma}$$

where ln represents a natural logarithm; λ represents a wavelength; σ represents an induced emission sectional area; τ_{sp} represents natural life of emission; and c represents speed of light.

[0045]

Since the fluorine laser normally operates under a high pressure in the range from 4 to 12 atm, fluorine molecules excited thereby are deactivated by collisions, and a substantial high level life τ thereof becomes shorter than the

natural life of emission τ_{sp}. Therefore, Equation 1 can be approximated by Equation 2 where τ_c represents the life after collisions.

[0046]

[Su 2]

$$\tau^{-1} = \tau_{sp}^{-1} + \tau_c^{-1}$$

A waveband $\Delta\lambda(P)$ that reflects a gas pressure P is inversely proportionate to the substantial high level life τ as expressed by Equation 3.

[0047]

[Su 3]

$$\Delta\lambda(P) \propto \tau^{-1}$$

Further, since it is considered that the inverse of the life τ_c after collisions (i.e., the speed of deactivation attributable to collisions) is proportionate to the pressure, the waveband $\Delta\lambda(P)$ can be expressed by Equation 4 where $\Delta\lambda0$ represents the waveband under a pressure P0.

[0048]

[Su 4]

$$\Delta\lambda(P) = \Delta\lambda_0 \frac{\tau_{sp}^{-1} + \tau_c^{-1}P/P_0}{\tau^{-1}}$$

It is assumed here that τ_{sp} = 3.7 ns and τ = 1 ns from the disclosure of the above-cited reference 1, and those values are substituted in Equation 4. Further, values of P and P0 that give a value of 0.25 or less when P/P0 is calculated (when

the gas pressure P according to the related art is in the range from 4 to 10 atm, the gas pressure P0 is in the range from 0.4 to 1.0 atm) are substituted in Equation 4. As a result of a calculation of Equation 4 with such substitutions, the waveband $\Delta\lambda(P)$ that reflects the gas pressure P is deceased to a $\Delta\lambda 0$ value of about 0.3 or less.

[0049]

Specifically, according to the related art, when the gas pressure is 4 atm, an oscillation beam from the fluorine laser has a waveband ($\Delta\lambda 0$) of about 1 pm. Therefore, the waveband can be narrowed to about 0.3 pm by decreasing the gas pressure to 1 atm or less.

[0050]

Fig. 2 shows the relationship between the waveband $\Delta\lambda(P)$ and the gas pressure P, i.e., the dependence of the waveband $\Delta\lambda(P)$ on gas pressures found by calculating Equation 4 with substitutions of P/P0 values where P0 is fixed at 4 atm and where P is varied to desired barometric pressures in the range from 0 to 4, e.g., 0, 1, 2, 3 and 4.

[0051]

In the system for causing discharge across the optical axis of laser light in the laser chamber (i.e., in a direction perpendicular to the direction of the optical axis), i.e., the transverse excitation system, since the interval between the cathode and anode is small (e.g., in the range from 10 to 20

mm), the discharge voltage must be decreased when the gas pressure is decreased in order to prevent the occurrence of arc discharge between those electrodes, which results in a reduction of the laser power. For example, when the gas pressure is decreased from 4 atm to 1 atm, a discharge voltage of about 20 KV must be decreased to about 10 KV.

[0052]

Fig. 3 is a graph showing the dependence of laser power on discharge voltages. In a laser chamber 15 to be described later, as shown in Fig. 3, the laser power increases with the discharge voltage when the gas pressure is constant. When the gas pressure is decreased, the maximum power of laser light decreases at the decreased pressure because the upper limit of the discharge voltage is decreased. That is, in the laser chamber 15, a laser operation occurs within the shaded range indicated by reference number 31 in Fig. 3.

[0053]

As understood by referring to Fig. 3, when the gas pressure is decreased from 4 atm to 1 atm, the discharge voltage of the laser chamber 15 must be decreased to a degree at which no arc discharge occurs, and this is accompanied by a reduction in the laser power.

[0054]

In the present embodiment, the ultra-narrow band fluorine laser apparatus 100 is formed by two fluorine laser

devices; a laser operation is performed in the first laser device with the gas pressure decreased to 1 atm or less; and the second laser device amplifies the power of laser light whose waveband has been narrowed to about 0.3 pm and whose power has been decreased.

[0055]

The description will continue with reference to Fig. 1 again. An oscillator/amplifier of the ultra-narrow band fluorine laser apparatus 100 is formed by an oscillator 11 and an amplifier 12.

[0056]

In the oscillator 11, the laser chamber 15 is provided in a stable type resonator constituted by an output mirror 13 and a totally reflecting mirror 14.

[0057]

The laser chamber 15 is filled with a laser gas including fluorine at about 0.8 atm. As a result, when discharge (glow discharge) is caused between electrodes in the laser chamber 15 to oscillate the laser, laser light L10 having a wavelength of 157.6299 nm and a waveband of about 0.3 pm (see Fig. 2) is obtained.

[0058]

The laser power of the laser light L10 is as small as 1 mJ or less and is not usable for exposure as it is. The reason is that laser power decreases proportionately to the gas

pressure.

[0059]

In the present embodiment, the power of the laser light L10 is increased using an amplifier 12. In an amplifier 12, a resonator is formed by a concave mirror 17 with a hole and a convex mirror 16, and a laser chamber 18 is provided in the resonator.

[0060]

The laser light L10 enters through the concave mirror 17 with a hole and is amplified as it travels in the laser chamber 18, and laser light L20 is obtained around the convex mirror 16.

[0061]

The laser light L20 has increased laser power of 10 mJ or more, although the waveband remains at about 0.3 pm because it has a spectrum similar to that of the laser light L10. The laser light L20 has sufficient power (laser power) to use for exposure.

[0062]

As described above, the waveband of the ultra-narrow band fluorine laser apparatus 100 is narrowed to about 0.3 pm by using the fluorine laser oscillator 11 with the gas pressure significantly decreased from a normal value, and a two-stage configuration formed by the oscillator 11 and amplifier 12 is employed to maintain laser power similar to that in the related

art.

[0063]

In the above-described embodiment, a gas such as xenon (Xe) may be added in the laser chamber 15 of the oscillator 11. Since this encourages preliminary ionization, there may be some improvement of the laser power of the oscillator 11.

[0064]

As described above, the ultra-narrow band fluorine laser apparatus 100 of the present embodiment is capable of generating laser light in a waveband as narrow as 0.3 pm or less without using element for achieving a narrow band such as an etalon.

[0065]

Further, since the narrow band is achieved while decreasing the total pressure of the laser gas, an oscillation beam with a narrow band is located substantially in the middle of the initial spectral distribution. That is, since no fluctuation of a central wavelength of the oscillation beam with a narrow band occurs as a result of a temperature rise at the band-narrowing element, there is no need for stabilizing means for stabilizing the wavelength. This makes it possible to simplify the laser apparatus.

[0066]

The use of the two fluorine laser devices makes it possible to achieve injection locking wherein the

oscillator/amplifier or oscillator serves as a seed laser. As a result, the first fluorine laser device narrows the waveband to about 0.3 pm and, even if laser light having low laser power is output, the laser power can be amplified by the second fluorine laser apparatus.

[0067]

Further, by keeping the total pressure of the laser gas in the laser chamber of the first oscillator (or seed laser) at 1 atm or less, it is possible to prevent leakage of fluorine gas (which is a gas harmful to a human body) from the laser chamber, thereby improving safety.

[0068]

[Second Embodiment]

Fig. 4 is an illustration of a configuration of an ultra-narrow band fluorine laser apparatus 200 according to a second embodiment of the invention.

[0069]

The second embodiment is the same as the first embodiment in that a fluorine laser is operated with the total pressure (hereinafter referred to as "gas pressure") of the laser gas kept at 1 atm or less to generate laser light with a waveband narrowed to about 0.3 pm.

[0070]

The present embodiment employs the longitudinal excitation system to be detailed later unlike the first

embodiment which employs the transverse excitation system. By employing the longitudinal excitation system, a long interval is set between the cathode and anode in the laser chamber without decreasing the discharge voltage to be applied between the electrodes when the gas pressure is decreased, thereby suppressing the occurrence of arc discharge between those electrodes.

[0071]

As shown in Fig. 4, the ultra-narrow band fluorine laser apparatus 200 has a stable resonator which is a resonator constituted by an output mirror 21 and a totally reflecting mirror 22 and containing a laser chamber 23. The laser apparatus has the same configuration as that of the oscillator 11 of the ultra-narrow band fluorine laser apparatus 100 shown in Fig.1.

[0072]

However, the longitudinal excitation system is employed in which a pair of electrodes, i.e., a cathode 24 and an anode 25 are arranged in the laser chamber 23 in a direction in parallel with laser light L30, i.e., the direction of the optical axis of the laser light L30. The shaded part indicated by reference number 201 is a discharge area. The laser gas flows in the shaded part in a direction perpendicular to the plane of Fig. 4, and a fan 26 is provided for this purpose.

[0073]

Since the ultra-narrow band fluorine laser apparatus 200 employs such a longitudinal excitation system, the interval between the cathode 24 and anode 25 is incomparably longer than that in a normal transverse excitation system. For example, while the electrode interval in a normal transverse excitation system is in the range from 10 to 20 mm, the electrode interval can be extended to about 1000 mm in the longitudinal excitation system of the present embodiment, which means that the electrode interval can be 50 to 100 times longer than that in the related art.

[0074]

Therefore, arc discharge is unlikely to occur and glow discharge can be maintained even if the pressure of the laser gas charged in the laser chamber 23 is very low. As a result, the output mirror 21 emits laser light L30 which has a wavelength of 157.6299 nm and whose oscillation beam waveband is as narrow as about 0.3 pm.

[0075]

Since the electrode interval in the transverse excitation system is as small as the beam height of laser light (e.g., in the range from about 10 to 20 mm) as described above, the discharge voltage must be low (e.g., 10 KV) when the gas pressure is decreased to 1 atm in order to prevent the occurrence of arc discharge at the electrode interval, and this results in reduced laser power (e.g., 1 mJ).

[0076]

On the contrary, in the longitudinal system, arc discharge is unlikely to occur because a long electrode interval (e.g., on the order of 1000 mm) can be set. That is, since discharge can be caused at a high discharge voltage (e.g., 20 KV), for example, glow discharge continues instead of changing to arc discharge even if the discharge voltage is increased as apparent from the characteristic represented by dotted line indicated by reference number 32 in Fig. 3 when the gas pressure is, for example, 1 atm. Therefore, the laser power can be increased.

[0077]

The ultra-narrow band fluorine laser apparatus 200 can be used in substitution for the oscillator 11 of the ultra-narrow band fluorine laser apparatus 100 shown in Fig. 1. In this case, since the laser power of laser light from the oscillator 11 can be increased, the amplifying characteristics of the amplifier 12 is also improved.

[0078]

In summary, either the transverse excitation system or the longitudinal excitation system may be used for the oscillator 11 of the ultra-narrow band fluorine laser apparatus 100 shown in Fig. 1.

[0079]

As described above, the second embodiment provides the

same effects as the first embodiment in that laser light in a waveband as narrow as 0.3 pm or less can be generated from the ultra-narrow band fluorine laser apparatus 200 without using a band-narrowing element such as an etalon.

[0080]

Since the narrow band is achieved with the total pressure of the laser gas decreased, no fluctuation of a central wavelength of the oscillation beam with the narrow band occurs as a result of a temperature rise at the band-narrowing element, and the central wavelength is located substantially in the middle of the initial spectral distribution. This eliminates the need for stabilizing means for stabilizing the wavelength, thereby allowing the laser apparatus to be simplified.

[0081]

Further, in the second embodiment, the electrode interval can be set at a length such that no arc discharge is caused (i.e., a long discharge length can be set) even if the gas pressure is sufficiently decreased because the longitudinal discharge (longitudinal excitation system) is used in which discharge occurs in the same direction as the direction of the optical axis of oscillated laser light. This makes it possible to maintain glow discharge which causes laser oscillation.

[0082]

[Third Embodiment]

Fig. 5 is an illustration of a configuration of a fluorine exposure machine 300 utilizing an ultra-narrow band fluorine laser apparatus.

[0083]

The fluorine exposure machine 300 is generally constituted by an ultra-narrow band fluorine laser apparatus 100 as shown in Fig. 1 and an exposure machine main body 110.

[0084]

The exposure machine main body 110 is provided on a grating 41 in a clean room, and the ultra-narrow band fluorine laser apparatus 100 is provided on a floor 42 (a floor generally referred to as "under floor") under the grating 41.

[0085]

Laser light L20 having only intense lines (oscillation beams) in a waveband of about 0.3 pm provided by the ultra-narrow band fluorine laser apparatus 100 travels upward after being reflected by a mirror 43a, passes through an aperture 44 of the grating 41 and enters the exposure machine main body 110.

[0086]

The laser light L20 travels in a glass rod 46 made of calcium fluoride after being converged by a lens 45. The light is subjected repeated total reflection in the rod and is emitted as laser light L21 having a uniform beam intensity distribution.

[0087]

The laser light L21 is reflected by a mirror 43b, passed through a beam shaper 47 which expands the beam cross section, reflected further by a mirror 43c and passed through a condenser lens 48 to be projected upon a reticle 49.

[0088]

After exiting the reticle 49, the laser light L22 passes through a reducing projection lens 50 to impinge upon a wafer 51. That is, a pattern in the reticle 49 is transferred by the reducing projection lens 50 on to the wafer 51 to cause exposure in the configuration of the pattern in reticle 49. The wafer 51 is placed on a stage 52.

[0089]

The fluorine exposure machine 300 of the third embodiment uses the reducing projection lens 50 as a reducing projection optical system, and the reducing projection lens 50 is constituted by a monochrome lens made of calcium fluoride.

[0090]

A reducing projection optical system constituted only by a lens can be used as described above because the laser light L20 provided by the ultra-narrow band fluorine laser apparatus 100 has a waveband of about 0.3 pm which is a small fraction of that of a fluorine laser according to the related art and the chromatic aberration of the reducing projection lens 50 is negligible.

[0091]

Therefore, the exposure main body 110 has a configuration similar to that of a KrF exposure machine according to the related art. Since the only significant difference is the change of the lens material from quartz to calcium fluoride, the reducing projection lens can be designed similarly to that in the related art, which makes it possible to reduce costs significantly.

[0092]

As described above, the fluorine exposure machine of the third embodiment of the invention can employ a totally refractive reducing projection optical system without any significant increase in the cost of the fluorine laser apparatus (ultra-narrow band fluorine laser apparatus) and without any significant reduction in the efficiency of the laser.

[0093]

That is, the reducing projection optical system can be designed similarly to that of a KrF exposure machine according to the related art. Therefore, a simulation tool similar to those in the related art can be used to allow the reducing projection optical system to be designed in a short period and to allow a significant reduction in labor cost. This makes it possible to merchandize a fluorine exposure machine in a short period at a low cost.

[Brief Description of Drawings]

[Fig. 1]

Fig. 1 is an illustration of a configuration of an ultra-narrow band fluorine laser apparatus according to a first embodiment of the invention.

[Fig. 2]

Fig. 2 is a graph showing the dependence of a waveband on gas pressures.

[Fig. 3]

Fig. 3 is a graph showing the dependence of laser power on voltages.

[Fig. 4]

Fig. 4 is an illustration of a configuration of an ultra-narrow band fluorine laser apparatus according to a second embodiment of the invention.

[Fig. 5]

Fig. 5 is an illustration of a configuration of a fluorine exposure machine according to a third embodiment of the invention.

[Explanation of Reference Numerals or Signs]

11	Oscillator
12	Amplifier
15, 23	Laser chamber
24	Cathode
25	Anode

100, 200	Ultra-narrow band fluorine laser apparatus
110	Exposure machine main body
300	Fluorine exposure machine
L10, L20, L21, L22, L23	Laser light

[Designation of Document] Drawing

[Fig. 1]

Illustration of Configuration of First embodiment

100 Ultra-narrow band fluorine laser apparatus

14 Totally reflecting mirror

11 Oscillator

15 Laser chamber

13 Output mirror

17 Concave mirror with a hole

12 Amplifier

18 Laser chamber

16 Convex mirror

[Fig. 2]

Graph showing Dependence of Waveband and Gas Pressure

Waveband (relative value)

Gas Pressure (atm)

[Fig. 3]

Graph showing Dependence of Laser Power on Voltage

Laser Output (relative value)

Voltage (relative value)

1 atm, 2 atm, 4 atm, 6 atm, 8 atm, 10 atm

[Fig. 4]

Illustration of Configuration of Second Embodiment

200 Ultra-narrow band fluorine laser apparatus

22 Totally reflecting mirror

24 Cathode

23 Laser chamber

26 Fan

25 Anode

21 Output mirror

[Fig. 5]

Illustration of Configuration of Third Embodiment

300 Fluorine exposure machine

110 Exposure machine main body

47 Beam shaper

43b Mirror

43c Mirror

48 Condenser lens

49 Reticle

46 Glass rod

50 Reducing projection lens

41 Grating

51 Wafer

45 Lens

52 Stage

44 Aperture

100 Ultra-narrow band fluorine laser apparatus

43a Mirror

42 Floor

[Designation of Document] Abstract

[Abstract]

[Problem] An ultra-narrow-band fluorine laser apparatus in which a line width of a fluorine laser can be narrowed to about 0.2 to 0.3 pm without using any band-narrowing element such as an etalon is to be provided.

[Means for Resolution] In an oscillator 11, a laser chamber 15 is provided in a stable type resonator constituted by an output mirror 13 and a totally reflecting mirror 14. The laser chamber 15 is filled with a laser gas at about 0.8 atm. As a result, when discharge is caused in the laser chamber 15 to cause laser oscillation, laser light L10 in a waveband of about 0.3 pm is provided. The power of the laser light L10 is increased by an amplifier 12. The amplifier 12 emits laser light L20 in a waveband of about 0.3 pm having laser power of 10 mJ or more.

[Selected Drawing] Fig. 1

VERIFICATION OF TRANSLATION

The undersigned, [insert name & address] Katsutoshi Sakashita, Tokyo, Japan declares that:

He is knowledgeable in the English and Japanese languages and that he believes the attached English translation is to his knowledge and belief, a complete and true translation of Japanese patent application 11-190490, filed July 5, 1999.

All statements made herein of his own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful and false statements may jeopardize the validity of the application or any patent issued thereon.

11/19/2002
Date

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